equivalent to a given thickness of copper. The ratio of the equivalent thicknesses of aluminium and copper changes a great deal in this short wave-length region of the X-ray spectrum. In the neighborhood of wave-length .3, for instance, an aluminium plate must be twenty-eight times as thick as a copper plate in order to absorb the same fraction of X-radiation. For wave-length .095, however, a plate of aluminium only 6 times as thick as a plate of copper will absorb the same fraction of X-radiation. The estimate of the equivalent thickness of aluminium and copper can be made comparatively easily and rapidly, so that the method furnishes a good means of determining the "effective" wave-length of a beam of X-rays during a treatment with them.

The curve giving the relation between the equivalent thickness and the wave-length will be published in a technical journal. The equivalent thickness for a given short wave-length can be calculated, of course, from equations (3), by dividing the linear coefficient of absorption for copper by that for aluminium.

The coefficient of absorption of a beam of rays that is not monochromatic usually (but not always) decreases as the rays pass through matter. If one measures the coefficient of absorption of such a beam, the results give a kind of average coefficient of absorption for the rays, as they travel through the absorbing material. Similarly, the above-mentioned methods of measuring the "effective" wave-lengths furnish a kind of average value for the "effective" wave-length of the beam as the rays pass through the plates.

[1] *Ithaca, Physic. Rev.*, August 1915, p. 166.

[2] *Ibid.*, Sept. 1916, p. 326.

[3] *Ibid.*, July 1921, p. 13.

THE EFFECTIVE TEMPERATURE OF 16 STARS AS ESTIMATED FROM THE ENERGY DISTRIBUTION IN THE COMPLETE SPECTRUM

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Communicated by V. M. Slipher, January 23, 1922

1. *Introductory Statement.*—Data on the spectral energy distribution of stars as related to that of a black body are very meager. They are the results practically of the spectrophotometric measurements of Wilsing,[1] and of Nordmann,[2] and the spectral energy curves determined photographically by Plaskett,[3] all of which relate to the visible spectrum.

The various methods used to obtain stellar temperatures give different results. For example, Plaskett (loc. cit.) obtained an effective temperature of 6800° K for *γ Cassiopeiae* (Class Bop) by considering the continuous spectrum and 10,600° K by considering the bright line spectrum.

In view of the fact that his continuous spectrum measurements terminated at 0.42 μ, where also is the observed maximum spectral energy, it is possible that the higher estimated temperature is the more nearly correct.

Wilsing, Scheiner and Münch (loc. cit.) also obtained a temperature of 6800° K for γ *Cassiopeiae*. Their temperature measurements of various stars of class *B* vary from 7000° to 15,000° K; class *A*, from 8000° to 12,000° K; class *F* from 5000 to 7000° K; class *G*, from 4000 to 5000° K; and class *M*, 3000° to 3500° K.

While it is to be expected that the various methods must give different results, it is interesting to find a rather close agreement in the estimated stellar temperatures. The agreement is especially close for stars of classes *G*, *K* and *M*, that is, stars having a low temperature.

In a previous paper,[4] data were given on a comparison of stellar radiometers and radiometric measurements of 110 stars using the Crossley reflector of the Lick Observatory at Mt. Hamilton, Calif., the altitude being about 4000 ft. Quantitative measurements were made on stars down to magnitude 5.3, and qualitative measurements to magnitude 6.7. It was found that red stars emit from 2.5 to 3 times as much *total* radiation as blue stars of the same visual magnitude.

These observations were verified by an independent method which consisted in measuring the transmission of stellar radiation through a 1-cm. cell of water, having quartz windows. By this means it was shown that of the *total* radiation emitted, blue stars have about 2 times as much *visible* radiation as yellow stars and about 3 times as much *visible* radiation as red stars.

2. *Experimental Procedure.*—In the present investigation the spectral energy distribution of a star was determined by means of a series of transmission screens, placed in front of a vacuum thermocouple which was used as the radiometer.

Screens were selected which, either singly or in combination, had a uniformly high transmission over a fairly narrow region of the spectrum terminating abruptly in complete opacity in the rest of the spectrum. By proceeding in this manner the observations required no correction other than that for surface reflection, which amounts to about 9 per cent for the two surfaces of the screen. Corrections were made for absorption by the telescope mirrors, also for atmospheric absorption, using the spectral transmission factors for the sun, as observed by Abbot and Fowle.

By means of these screens (of red and yellow glass, quartz and water) it was possible to obtain the radiation intensity in the spectrum (from the extreme ultra-violet, which is limited by atmospheric transmission and the low reflectivity of the telescope mirrors) at 0.3μ to 0.43μ; 0.43μ to 0.60μ; 0.60μ to 1.4μ; 1.4μ to 4.1μ; and 4.1μ to 10μ.

In this manner the distribution of energy in the spectra of 16 stars was

determined, thus obtaining for the first time an insight into the radiation intensities in the complete spectrum of a star.

3. *Results*.—By means of this device it was found that, in the class *B* and class *A* stars, the maximum radiation intensity lies in the ultra-violet (0.3μ to 0.4μ) while in the cooler, classes *K* and *M*, stars, the maximum emission lies at 0.7μ to 0.9μ in the infra-red. From this it appears that the black body temperature (i.e., the temperature which a black body would have to attain in order to emit a similar relative spectral energy distribution) varies from 3000° C for red, class *M*, stars to 10,000° for blue, class *B*, stars.

This estimate of the effective temperature of a star was obtained by two methods. The first method consisted in making all corrections to the observations, excepting those for atmospheric absorption, and comparing them with the calculated values, using a solar type star (α Aurigae, class *Go*) as a standard. This seems permissible, in view of the fact that the observed temperature (6000° K) of α Aurigae was found to be in close agreement with that assigned to the sun. The stellar temperatures estimated in this manner are given in column 4 of table 1.

The second method consisted in applying all corrections to the observations, including the one for atmospheric absorption, and comparing the results with the calculated values. Applying factors for atmospheric absorption introduces great irregularities in the observed spectral radiation components. This, no doubt, is owing partly to selective emission of the star, and partly to the use of improper transmission factors, which, because of lack of time, could not be determined directly.

The temperature of a star, as estimated from the spectral energy components outside of the atmosphere, extends over a wide range, the average value of which is in good agreement with that obtained by the first method (see column 3 of table 1).

In table 1 are assembled the effective stellar temperatures as determined by various methods. The agreement is especially close for stars of classes *G*, *K* and *M*.

Most of the stars measured are no doubt giants, of which Russell[5] says: "The mean densities of the giant stars diminish rapidly with increasing redness, from one-tenth that of the sun for class *A* to less than one-twenty-thousandth that of the sun for class *M*." In speculating on the nature of stellar radiation and stellar temperatures it is interesting to find that the observed radiometric data (see table 2) seem conclusive in showing that the early type (class *M*) stars are losing heat 3 to 4 times as fast as the more dense, but hotter late-type (class *B*, *A*) stars. The least dense, class *M*, stars must therefore be losing heat by radiation, in which conduction cannot contribute very materially in maintaining the surface at a given temperature.

In the dense stars the shape of the spectral energy curve, and hence our inference of the effective temperature is determined by the spectral emissivity of the surface; while in the less dense stars the radiation emanates from great depths.

TABLE 1

STELLAR TEMPERATURES

STAR	CLASS	COBLENTZ Calculated	COBLENTZ Class *Go* as Standard	WILSING, SCHEINER & MÜNCH	NORDMANN & LEMORVAN	NORDMANN
ϵ Orionis	Bo	13000 to 14000° K	13000° K			
β Orionis	B8p	10000 to 12000	10000			
α Lyrae	Ao	8000 to 10000	8000	9400° K		12200° K
α Canis Majoris	Ao	8000 to 11000	8000			
α Cygnii	A2	8000 to 10000	9000	9400		
α Aquilae	A5	7000 to 9000	8000	8100		
α Canis Minoris	F5	5500 to 7500	6000	7200		
α Aurigae	Go	5300 to 6500	6000	7100		
α Boötis	Ko	3500 to 4500	4000	3700		
β Geminorum	Ko	4500 to 7000	5500	4900		
α Tauri	K5	2800 to 4500	3500	3500	3600	3500
α Orionis	Ma	2800 to 3300	3000	3000		
α Scorpii	Map	2500 to 3200	3000			

β Andromedae	Ma	3500 to 4500	4000	3200	4300	3700
μ Geminorum	Ma	2500 to 3300	3500	3100	3200	
β Pegasi	Mb	2500 to 3200	3000	2800		
Sun	Go		5800* to 6200			5320

* Recalculated from Abbot & Fowle, *J. Opt. Soc. Am.*, **5**, 1921 (272).

Through the generosity of Drs. V. M. Slipher and C. O. Lampland, the present data were obtained during the past summer, using the 40-inch reflector of the Lowell Observatory, at Flagstaff, Arizona, altitude 73,000 ft. Dr. Lampland personally operated the telescope, thus insuring speed and efficiency. It is a pleasure to record here my grateful acknowledgment for the many courtesies extended me by various members of the Observatory Staff.

TABLE 2

COMPARISON OF THE TOTAL RADIATION FROM STARS HAVING CLOSELY THE SAME VISUAL MAGNITUDE

STAR	SPECTRAL CLASS	VISUAL MAGNITUDE	GALVANOMETER DEFLECTION CM.
ε Geminorum	G5	3.18	0.58
μ Geminorum	Ma	3.19	2.11
β Geminorum	Ko	1.21	2.19
α Scorpii	Map	1.22	8.82
α Aquilae	A5	0.90	1.89
α Tauri	K5	1.06	6.03
α Orionis	Ma	0.92	15.0
ρ Ophiuchi	Ko	2.94	0.37
δ Ophiuchi	Ma	3.03	1.37
γ Leonis	Ko	2.61	0.99
β Pegasi	Mb	2.61	2.96
α Coronae Borealis	Ao	2.32	0.48
β Ursa Majoris	Ao	2.44	0.37
γ Draconis	K5	2.42	1.65
α Aurigae	Go	0.21	4.91
α Boötis	Ko	0.24	8.10

[1] Wilsing, Scheiner and Münch, *Publ. Astrophys. Obs., Potsdam*, **24**, 1920 (No. 74).

[2] Nordmann, Paris, *Compt. Rend.*, **149**, 1009 (1038). Nordmann and LeMorvan, *Ibid.*, **173**, 1921 (62).

[3] Plaskett, *Mon. Not. R. A. S.*, **80**, 1920 (771).

[4] Coblentz, *Washington, Bur. Standards, Bull.* **11**, 1914 (613).

[5] Russell, *Pop. Astron.*, **22**, Nos. 5 and 6, 1914.